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A METHOD FOR DETERMINING MISSION RE-ENTRY TIMES FOR FALLOUT-CONTAMINATED INDUSTRIAL COMPLEXES

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ADMINISTRATIVE INFORMATION

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ABSTRACT

In the event of a nuclear war, knowledge of the time of availability, after contamination by fallout, for re-entry and use of certain resources is important in planning and preparing for the nation's recovery. This study is limited to the estimation of the availability time for industrial complexes that are not physically damaged by the attack or by emergency shut-down, but are inaccessible because of radiological contamination by fallout. A method of calculation proposed to be suitable for all industrial complexes was applied to five petroleum refineries. The findings were that the dose to decontamination personnel is the primary factor limiting re-entry and use. For the standard intensity range of 100 to 30,000 r/hr and dose limits of 30 r/24 hr, 230 r/2 wk and 1,000 r/yr, the mission re-entry time for the refineries studied ranged from 1 to 35 days.

SUMMARY

The Problem

Determine the earliest permissible re-entry times (within pre-set exposure limits) for industries contaminated by fallout. Explore the problem for petroleum refineries.

Findings

A method was devised to estimate re-entry times for undamaged (either by the attack or by emergency shut-down) contaminated target complexes. In this method, calculations of the exposure dose to decontamination and mission personnel with respect to time after attack are utilized.

The earliest permissible re-entry times for the five petroleum refineries studied and for specified conditions of standard intensities from 100 to 30,000 r/hr and dose limits of 30 r/(24 hr) day, 230 r/2 wk and 1000 r/yr, ranged from 1 to 35 days.

1. INTRODUCTION

1.1 Objective

Provide the earliest permissible mission re-entry times (the earliest time after attack that plant personnel may re-enter to resume their activities) for undamaged* industrial complexes incapacitated by radioactive fallout. The range of standard intensities of interest is 100 to 30,000 r/hr. Dose to personnel shall not exceed 30 r/24 hr, 230 r/2 weeks, and 1000 r/year. Explore petroleum refineries for the initial study.

Describe the method of analysis determined for use in predicting the earliest permissible re-entry times.

1.2 Background

Re-entry into a fallout-contaminated area within permissible dose limits may be attained by (1) awaiting the reduction of dose rate by the natural decay processes of fission products, or (2) reducing the dose rate by decontamination. The permissible re-entry time may be hastened by decontamination for many dose criteria.

The mission re-entry time is that time when plant personnel (production and maintenance) return to the installation to initiate activities towards producing a product. The earliest permissible mission re-entry time should not be confused with the decontamination entry time or the time that partial or full production is resumed. The time lapse between decontamination entry and mission re-entry is that time needed for decontamination; the time lapse between mission re-entry and partial or full production will not only depend upon the industry, but will depend upon any particular plant within the industry.

Some plants will require extensive repairs after an emergency shut-down or a long down-time before resuming partial or full production. Others will not. The design and mode of operations, the length of

*Undamaged either by the attack or by emergency shut-down.

down time, all affect the length of time required to resume production. Unless the various conditions are specified and many other influencing factors are assumed, a definite lapse-time between the mission re-entry and full production cannot be given. A study of the ramifications of this subject for petroleum refineries, have been pursued by Mr. L. J. P. Minvielle and Mr. W. H. Van Horn* of NRDL.

1.3 Concept of Problem Conditions

The first type of industrial plant studied was petroleum refineries because their main products, various types of fuel, are so vital to the nation's ability to recover; it is assumed that other industries may be studied similarly.

Before proceeding with the problem of applying a prediction method and providing earliest permissible mission re-entry times, it is necessary to define more clearly the conditions under which the permissible re-entry need be determined.

First, it is assumed that we have been attacked in a nuclear war. It is also assumed that although a target complex of interest has not been damaged by weapon blast or fire, fallout has been deposited upon it. It is realistic to assume that fallout also has occurred in the surrounding areas.

For the standard intensity range presented for investigation it must also be assumed that adequate shelter has been available to all personnel involved, otherwise the dose limits would have been exceeded at the start. Since shelters are only a part of a defense system, and adequate shelters are assumed available, it is reasonable to assume further that the people have been trained for such an emergency and that supplies and provisions have been made available for survival and eventual rehabilitation. It may be assumed also in such a state of national preparedness, that the industrial installations would have made certain vital preparations for decontamination, etc. so that they may readily recover, if possible, from the effects of a nuclear attack.

The alternative consideration is that adequate shelters were not available and that the people normally located near the industrial complex of interest had either evacuated prior to attack or were exposed to the effects of the attack and that their services can no longer be called upon. If such a situation is assumed, people from outside the

*A report is being prepared on recovery of petroleum refineries after nuclear attack.

destruction and fallout areas must be called upon to enter and recover and operate the industry. To solve the problem under these circumstances imposes another set of calculations, because the dose received enroute to the industrial complex must be figured. The scope of the problem must then be enlarged to include details of the dose rates enroute, the mode of travel, distance of travel, and time of travel. The results from such calculations will not lend themselves to providing general solutions. Furthermore, concepts of evacuation or of a shelterless, fallout-free haven for a large portion of the population lack credibility. Therefore, this study will assume that the former conditions of readiness described exist.

1.4 Physical Characteristics of Industrial Complexes

The effort and effect of decontamination depend a great deal upon the physical characteristics of the industrial complex to be recovered. The physical layouts of industrial plants vary. In some light industries, plants are entirely enclosed in a single large structure; in some heavy industries, plants include a vast array of work areas both indoors and outdoors, and may occupy many acres. The method required to be developed to provide estimates of permissible mission entry times should be applicable to all types of industrial complexes for any contamination state.

Obtaining the earliest permissible mission re-entry time for an industrial complex centers about the recovery of only the vital areas, those areas which must be occupied and used. The non-vital areas, areas that will be used infrequently or may not be required until a later date, may be recovered after mission entry.

Petroleum refineries vary in size and complexity, but they do have many common characteristics. The petroleum refinery complexes are normally divided in two major component areas, (1) the distillation or refining area(s), and (2) the storage or tank area(s). Because the refining area must be constantly manned and is the area of intense human activity, it is the vital area that must be recovered. The storage area, usually located at some distance from the refining area, is only intermittently manned by a very limited number of men. This area is not a vital area.

Some refineries produce only fuel; others, fuel and various by-products. This study will be confined to the fuel-producing areas and shipping areas in refineries.

2 METHOD OF ANALYSIS

2.1 General

As previously stated, in some instances, the permissible mission re-entry time for contaminated areas may be made earlier through decontamination than through awaiting decay.

The available decontamination data allow a very detailed appraisal of time, effort, and dose expenditure for some components of a target complex but the lack of such data for other components and target complexes prevents such detailed appraisal. Petroleum refineries exemplify the latter situation. In this case, the vital areas within the complex were defined, and a decontamination rate and a decontamination effectiveness were estimated by extrapolating existing data to the intricate geometries encountered for all components, and were summarized. The results were reduced to gross estimates of rates and effectiveness, and the latter values were then used in calculating personnel dosages. The earliest permissible mission entry time within specified dosage limits was thus determined.

Several reasons justify this simplification:

a. The physical complexity of a petroleum refinery makes it very difficult to apply presently available rate and effectiveness data.

b. Some of the intricate geometries of surfaces have never been experimentally encountered nor recorded as decontamination experience.

c. The total time required for decontamination is short.

d. For the dose limits prescribed, a high degree of decontamination effectiveness is not required in most instances.

e. The sites of work of the mission personnel are not fixed, and since there will be hot and cold spots within their work areas, the dose rates experienced will vary individually with their movements within the complex.

f. The fallout distribution will not be uniform over such a complex.

2.2 Dose Equations

In this study the mission personnel (production personnel) are also decontamination personnel. Thus the problem of formulating the earliest permissible re-entry time involves all three radiological defense time-phases: the emergency phase when people are in shelters, the operational recovery phase, and the final recovery phase where mission operation has resumed. Within these three phases the dose limits apply at any time for the time periods specified. The dose equation for the three phases may be expressed as

$$D_1 + D_2 + D_3 = D_T \tag{1}$$

Because we are concerned with not only D_T, the total dose, or the dose received in any phase period, but also the dose received at any time for periods of 1 day, 2 weeks, and 1 year, the above equation is expanded to components more suitable for analysis

$$I_s (RN_1\, \Delta DRM_1 + RN_2 \Delta DRM_2 + RN_3 \Delta DRM_3) = D_T \tag{2}$$

where:

- I_s is the standard intensity.
- RN_1 is the residual number or protection factor of the shelter against fallout gamma radiation.
- RN_2 is the residual number or dose reduction factor for decontamination personnel during decontamination operations.
- RN_3 is the residual number or dose rate reduction accomplished by decontamination.
- ΔDRM_1 is the dose rate multiplier for phase 1 that takes into account the length of the phase period, as well as the effects of decay during the phase period.
- ΔDRM_2 is the dose rate multiplier for phase 2.
- ΔDRM_3 is the dose rate multiplier for phase 3.

ΔDRM may be compared with the dose equation for a decay of $t^{-1.2}$ as follows:

$$\frac{D}{I_s} = \int_{t_1}^{t_2} t^{-1.2}\, dt$$

The right-hand side of the equation is the ΔDRM for the period from t_1 to t_2. The reason the above equation is not used for dose calculations is that $t^{-1.2}$ is only an approximation of the actual

fission product decay. In order to obtain more accurate computation factors, the decay curve is integrated in parts and listed as accumulated values of DRM from 1 hr to some later time (10,000 hr) so that the total time of interest is covered. These values are shown in Fig. 1.* If the period of interest is from 7 to 83 hr, then the ΔDRM is the DRM value listed for 83 hr minus that for 7 hr.

Since the dose periods that need investigation may be any part of phases 1, 2 or 3, a further breakdown of Eq. 2 is normally necessary to determine the accumulated dose over the specified limit periods. This is begun by considering each phase separately.

2.3 Dose Limits Applied to the Emergency Phase

During the emergency phase, if shelters are inadequate then the prescribed dose limits would be exceeded, and within the concept of the problem the refinery cannot be recovered by the over-exposed people. If shelters are grossly adequate or if other, unexposed personnel are used during the later phases, the emergency phase dose (~ 0) does not enter into the solution of the problem. If the adequacy of the shelters is border-line, however, the dose received therein must be added to some later dose for any 2-week or 1-year period. In such cases, the dose in shelter must not exceed 30 r/day; otherwise the shelter is inadequate. With this restriction the significance of border-line situations is very limited. For instance if $I_s = 5000$ r/hr, then for the limiting dose of 30 r/day the maximum shelter RN_1 may be calculated as follows:

$$I_s \times RN_1 \times \Delta DRM_{1\ day} = D \qquad (3)$$

where the ΔDRM should be chosen for the highest 24-hr value. The ΔDRM from 1 to 25 hr is 2.1. To use this ΔDRM it is tacitly assumed that all the fallout in the area was deposited within 1 hr after detonation, a very unlikely condition.

Normally the dose received during the emergency phase is calculated in two parts. The first part is during the fallout event; the second, after fallout cessation. This being the case, a fallout rate is required to determine the emergency dose accurately. However, if it is assumed that the shelter stay-time is long compared with the fallout duration period, the dose received during the fallout period may be neglected in obtaining a value of approximate dose for a 24-hr period. The resultant required RN_1 value could be underestimated but not overestimated. To continue with the example, let it be assumed that

*From C.F. Miller's decay curve.

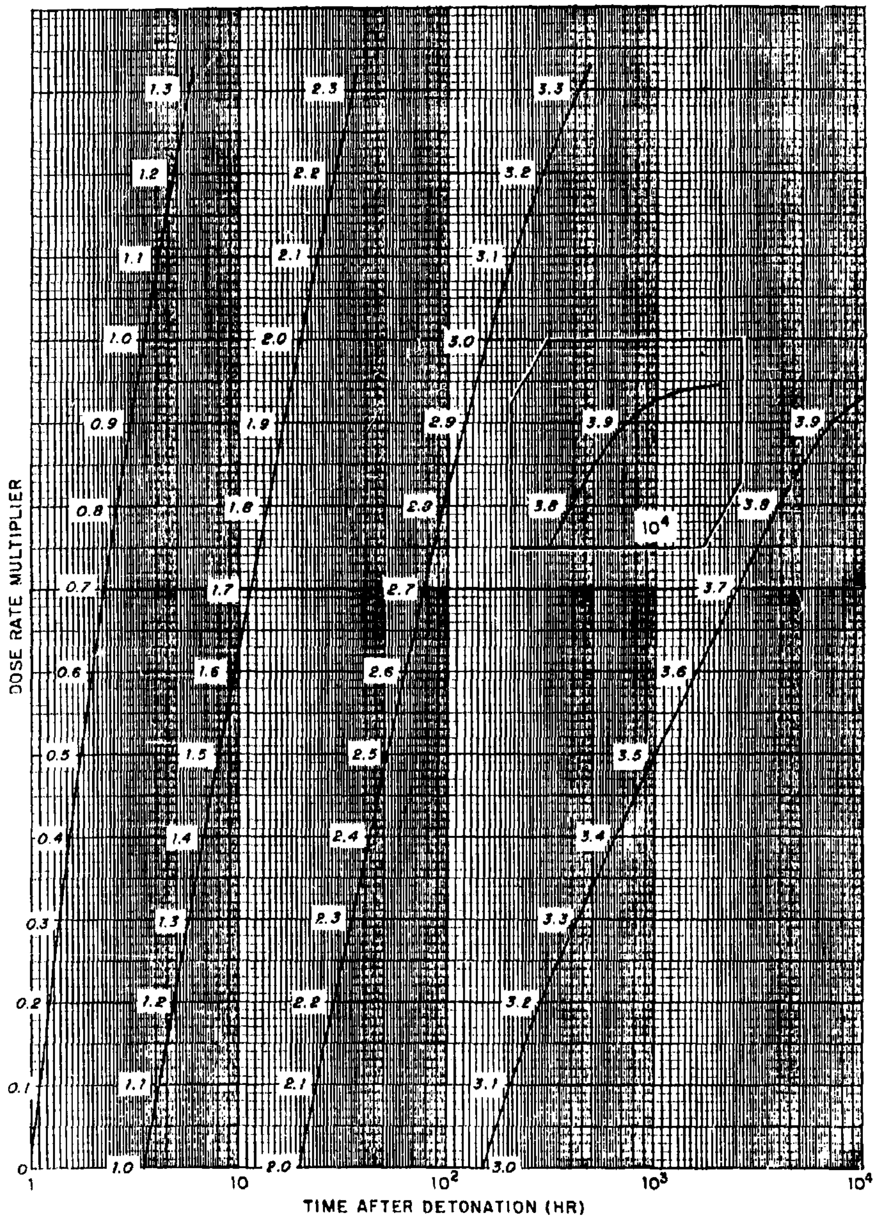

Fig. 1 Dose Rate Multiplier Curve

fallout cessation was at 5 hr after detonation and calculate the RN_1 value required for the ensuing 24 hr. The DRM at 29 hr is ~ 2.2. and the DRM at 5 hr is ~ 1.2.

$$\Delta DRM = 2.2 - 1.2 = 1$$

From Eq 3 the 1-day limiting

$$RN_1 = 30/5000 \times 1 = 0.006$$

Using this value of 0.006 and again applying Eq 3, the highest 2-week shelter dose may be calculated:

$$D_{2\ wk} = (3.12 - 1.2)\ 5000 \times 0.006 = 60\ r$$

If phase 1 does not last 2 weeks, then the highest dose obtained in phase 1 will be less than 60 r; consequently the dose received in a shelter that is barely adequate will contribute only a small amount to the permissible 230 r/2 wk limit or the 1000 r/yr limit.

2.4 Dose Limits Applied to the Operational Recovery Phase

In the operational recovery phase, for most applicable decontamination methods, the estimated RN_2 value (residual number during decontamination) is higher, by many times, than the expected RN_3 (residual number after decontamination) value for the method. Because the RN_2 value is high and the expected RN_3 value is much lower, and if shelters were adequate, the most likely time for the dose limit to be critical for short periods of time is during decontamination. This being the case, the next logical step is to obtain an estimate of the elapsed time required for decontamination.

Five oil refineries of various size, vintage, and operational methods were visited to obtain the vital data for estimating decontamination time. The information acquired on area sizes, complexity, manpower, and facilities was then integrated with available decontamination data and experience. Estimates of decontamination times were made from the following equation:

$$T_D = \frac{\text{area}}{\text{teams} \times \text{rate/team}}$$

This calculation was applied to the various component areas within the complex, dependent upon the manpower and decontamination facilities at each location. If it is assumed that personnel may be shifted to various locations and the decontamination facilities are adequate, then

$$T_D = \frac{\text{Total Vital area of Complex}}{\text{teams} \times \text{average rate/team}}$$

The solution requires an estimate of the total vital area of the complex, as well as an estimate of the average decontamination rate per team and the number of teams that can be gainfully employed. If the decontamination method is firehosing, available data on decontamination of open paved areas provide rates of 18,000 to 120,000 ft^2/hr for mass loadings to 100 g/ft^2, whereas rates for building roofs varied from 3600 ft^2/hr to 36,000 ft^2/hr dependent upon roof type.* The vital areas of petroleum refineries, however, are a maze of piping, structural members, and mechanical equipment. The decontamination rates above certainly could not be maintained. As previously stated, estimates of rate were made for the various component areas and a gross rate estimate for the entire vital area was obtained. The average rate of decontamination for a particular refinery was conservatively estimated at 2000 ft^2/hr.

The total vital area of this refinery was 6.5×10^6 ft^2. The water supply was 22,000 gpm at 125 psi and was distributed over the entire complex. The refinery had 2000 employees. If each firehose employed delivers 100 gpm, then 220 teams may be gainfully employed at all times. If each firehosing team requires 3 men, 660 men are required per shift and 3 complete work shifts may be formed. The required decontamination time

$$T_D = \frac{6.5 \times 10^6}{220 \times 2000} = 15 \text{ hr}$$

Because decontamination requires less than 1 day, the earliest entry time possible is determined by apportioning a 1-day limit (30 r) to the day of decontamination. Although the mission entry times for any standard intensity later may be dependent upon the restrictions imposed during phase 3, it cannot be any earlier regardless of the circumstances of phase 3. Since decontamination requires less than 1 day, the dose limits of 230 r/2 wk and 1000 r/yr are of primary concern only during phase 3. For a 2-week period that is part of all three radiological

*See Appendix B: H. Lee, Estimating Cost and Effectiveness of Decontaminating Land Targets - Vol I, Estimating Procedure and Computational Technique, USNRDL-TR-435, 6 June 1960.

defense phases, a fraction of 60 r will be accumulated during phase 1; 30 r will be accumulated executing phase 2; and the dose available for phase 3 is

$$(230 - 60x - 30)\ r$$

where x is a value less than 1.

The first set of estimates of mission entry time is calculated using the equation

$$30 = I_s\ RN_2\ \Delta DRM_2$$

where I_s = 100 to 30,000 r/hr
RN_2 = 0.75 (firehosing)*
ΔDRM_2 is for elapsed times of 5 hr (3 shifts of 5 hr each).

With this equation a decontamination start time (t_1) is found for all I_s values, and the mission re-entry time is equal to t_1 + 15 hr for this particular limiting condition. The results are shown in Fig. 2. It is assumed that on the day of decontamination all personnel remained in shelter or returned to shelter while not decontaminating.

2.5 Dose Limits Applied After Mission Re-entry

The final condition required to satisfy the problem is that mission personnel (phase 3) will not exceed the prescribed dose limits. Since the RN_3 fraction is smaller than the RN_2 value and the RN_2 value satisfied the 1-day dose limit, the 1-day dose limit during phase 3 will not be a restriction. The dose limits of 230 r/2 wk and 1000 r/yr, on the other hand, may provide an additional restriction and thus prolong the mission re-entry time. The mission re-entry time provided by phase 3 restrictions is calculated by using the equation

$$D_3 = I_s\ RN_3\ \Delta DRM_3$$

Because of the nature of the dose limits prescribed and because only a relatively short time is required for decontamination, there is very little reason why recovery personnel should not also be mission personnel. Again, if it is assumed that adequate shelters were available during phase 1 and that the dose received therein would have very

*Report in progress by J. D. Sartor and W. L. Owen on radiological recovery of land target complex I and II.

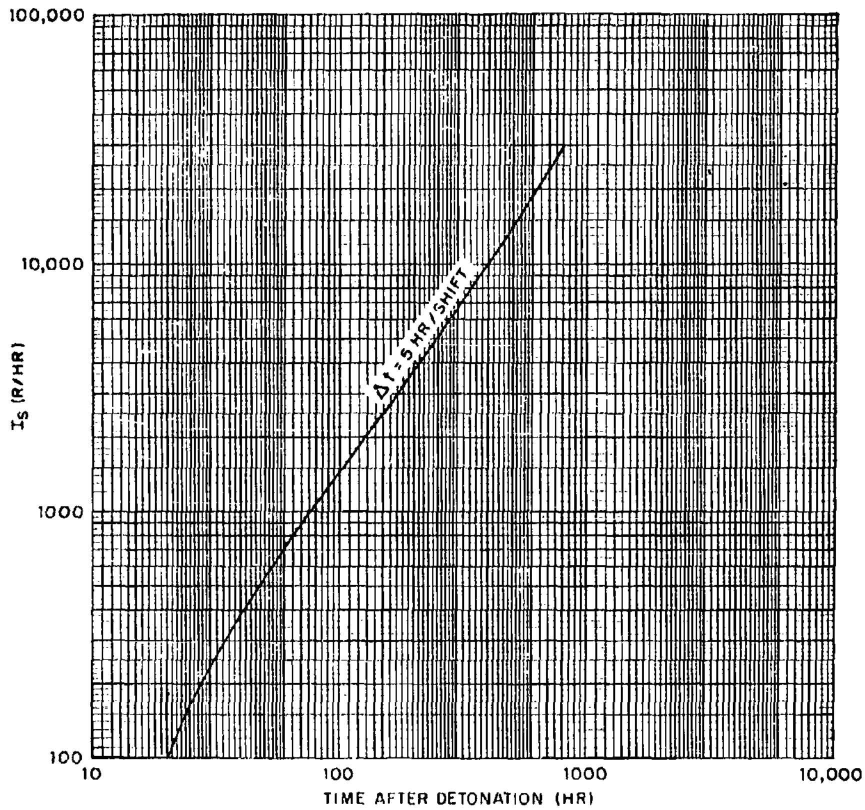

Fig. 2 Mission Entry Time for a Dose Limit of 30 r/day, 15 hr Decon Time, and $RN_2 = 0.75$

little bearing on the problem, we are concerned only with the dose received during phases 2 and 3. Since 30 r were expended on the day of decontamination, only 200 r is available for the next 13 days. No adjustment was deemed necessary for the 1-year calculation. An exploration of the problem was initiated by using RN_3 values of 0.2 and 0.1. The results are shown in Fig. 3 for the 2-week dose restriction, and Fig. 4 for the 1-year dose restriction.

3. RESULTS

The earliest permissible mission re-entry time for any standard intensity is the highest number of hours obtained from the three figures (Figs. 2, 3, and 4). Figure 5 combines the relevant portions of these three figures and provides the earliest mission re-entry time for all the conditions assumed. Table 1 provides the permissible mission re-entry times in terms of days and shows the decontamination effectiveness required for the re-entry times listed. Table 2 lists the mission re-entry times calculated for the five refinery complexes studied. Although the physical layouts and modes of operation for these five refineries were quite diverse their calculated mission re-entry times were very similar. It may be assumed that mission re-entry times for most refineries will not vary appreciably from that shown in Table 2. These results are based upon the assumption that a decontamination work shift less than 5 hr would not be efficient and that the earliest mission re-entry time may be obtained by calculating for the dose limit for the first day of operational decontamination and adding the elapsed decontamination time.

4. DISCUSSION

The findings for the five refineries were based upon estimates of the vital area size, decontamination rates, the residual numbers RN_2 and RN_3, and data on manpower and pertinent resources. The decontamination method chosen was firehosing. For some of the refineries, drainage through storm drains was adequate to handle the decontamination effort. In others it was not. Refineries with inadequate drainage could still be decontaminated by firehosing if drains and dumps were dug (bulldozed) at required locations.

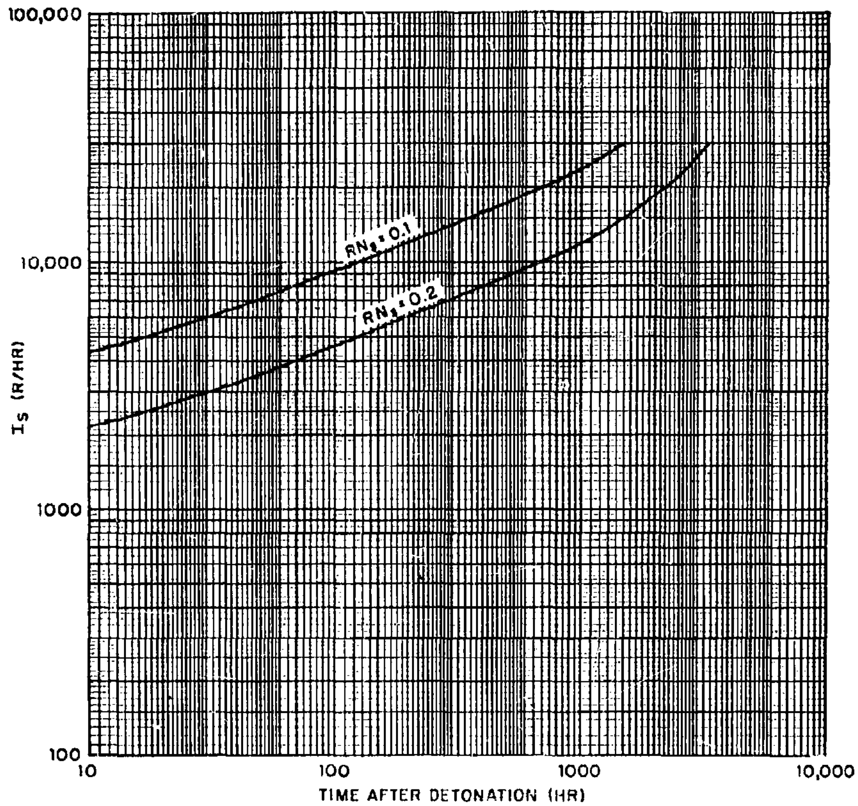

Fig. 3 Mission Entry Time for a Dose Limit of 230 r/2 wk

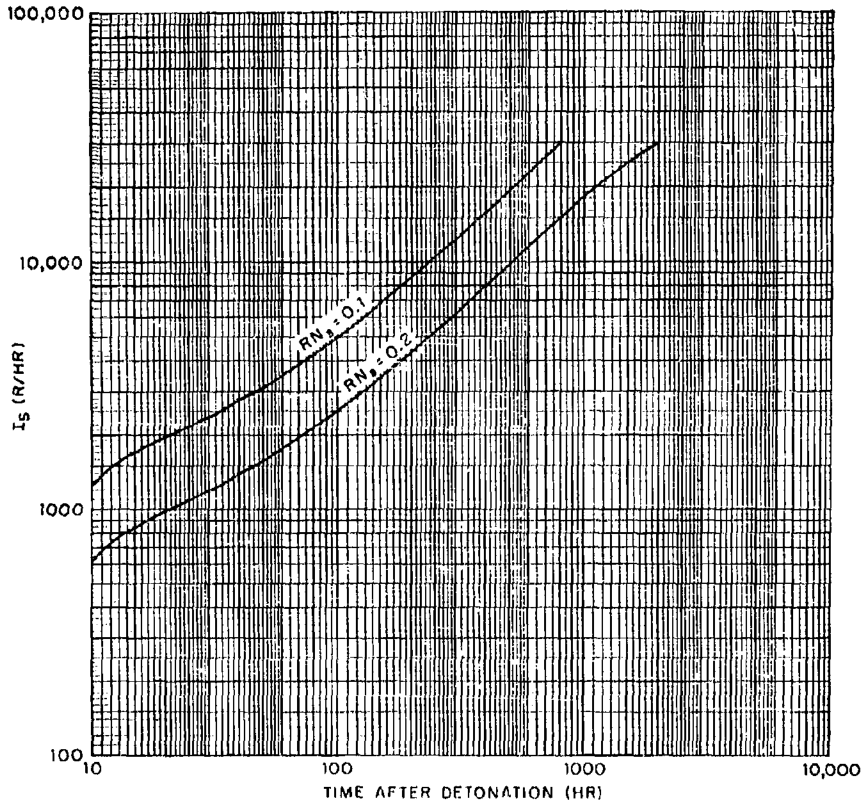

Fig. [illegible] M[illegible] F[illegible] [illegible] 1000 r/yr

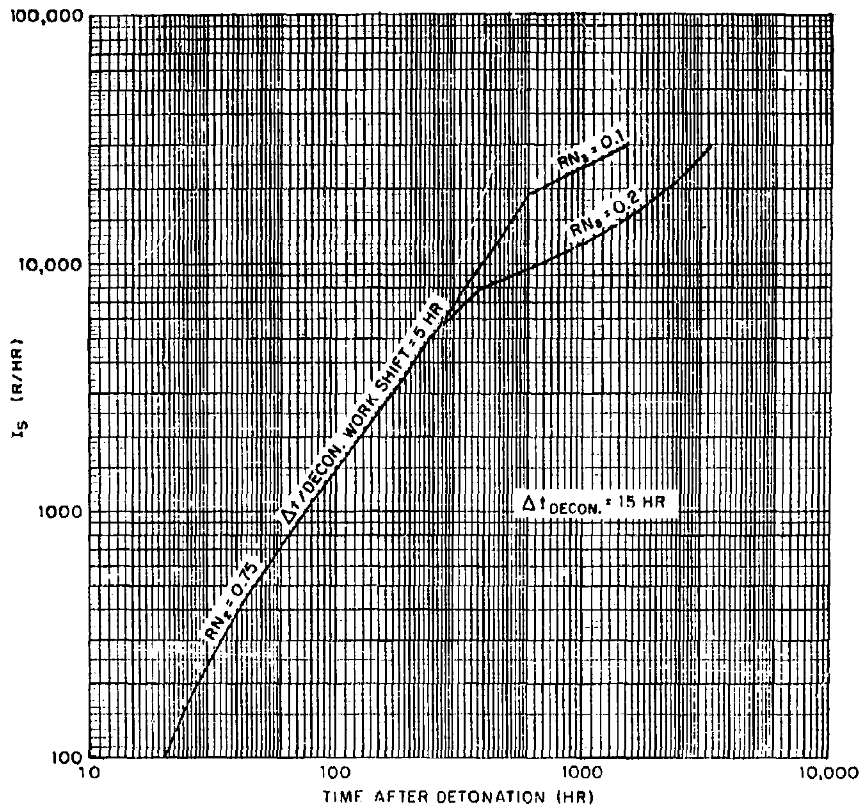

Fig. 5 Mission Entry Time for Dose Limits of 30 r/day, 230 r/2 wk and 1000 r/yr

TABLE 1

Mission Re-entry Time for Dose Limits of 30 r/day, 230 r/2 wk, and 1000 r/yr

I_s (r/hr)	Controlling RN	Required RN_3	t_e (approx. days)
100	RN_2	1	1
300	RN_2	0.69	2
1000	RN_2	0.34	4
3000	RN_2	0.23	7
10,000	RN_3	0.20 0.157	29 17
30,000	RN_3	0.20 0.10 0.07	137 62 34

Total decontamination time = 15 hr, (Firehosing 6.5×10^6 ft^2).
RN_2 = 0.75.
t_e = Mission re-entry time in days after attack.
No dose in shelter assumed.

TABLE 2

Mission Re-entry Times for Five Refineries for Dose Limits of 30 r/day, 230 r/2 wk and 1000 r/yr
(Undamaged* fuel-producing components only)

I_s (r/hr)	t_e (days)				
	Refinery[a]				
	1	2	3	4	5
100	1	2	2	1	2
300	2	3	3	2	3
1000	4	4	5	4	4
3000	7	8	9	7	8
10000	17	17	[illegible]	17	17
30000	34	35	35	34	35

a. The chief characteristics of the refineries are:

(1) 210,000 BPCD, Old and New Components, Vital area 6.5×10^6 ft^2, 2000 employed.
(2) 50,000 BPCD, New Plant, Vital area 3.2×10^6 ft^2, 500 employed.
(3) 50,000 BPCD, New Plant, Vital area 2.8×10^6 ft^2, 300 employed.
(4) 160,000 BPCD, Old Plant with few new components, a complete products plant, Vital area 4×10^6 ft^2, 4000 employed.
(5) 160,000 BPCD, Old Plant with few new components, mostly built over gravelled ground, Vital area 5×10^6 ft^2, 1700 employed.

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* Undamaged either by the attack or by emergency shut-down.

The amount of radioactive debris deposited, which would produce standard intensities greater than the 3000-r/hr value on which these findings are based, causes removal by firehosing to become increasingly difficult because of the greater mass of material that must be moved. Also since a uniform deposit cannot normally be expected, bulk removal by shovels and by some means of conveyance to some dump point will be required. This effort will normally require additional manpower or an extension of the decontamination time.

For the present, since we have no experience in decontamination for this type of complex, the estimates presented are the best that can be provided. Admittedly the findings were computed from poor input data, i.e., rather coarse estimates and loose use of basic data. However, high accuracy in analysis can be misleading in real situations, where mission re-entry will be delayed for a long period of time because of high standard intensities and the effects of weathering over this period cannot be accurately predicted for the many types of structures and geometries. It is only under these conditions (high I_s) that accurate effectiveness values are important for planning and that high effectiveness of decontamination is important for gaining early re-entry. Fortunately the expected RN_3 in highly contaminated areas is smaller than that obtainable for areas with less contamination. Also, for most of the range of standard intensities the earliest mission re-entry may be effected by a rather low order of decontamination effectiveness.

Another problem arises when standard intensities in the region of 10,000 r/hr and 30,000 r/hr are considered. It was tacitly assumed that the tank area would not require decontamination and that a method of switching personnel and scheduling exposure would suffice. The decay rate after mission re-entry is slow, and since a long stay is anticipated (1 year), dose economics may require that some decontamination be undertaken in the tank areas for high standard intensities.

All the tank areas of the refineries visited covered a relatively large portion of the plant area. Besides the great expanse, the areas were of the nature that they would be very difficult to decontaminate by any single quick method. Some areas could be firehosed; other areas would require motorized scrapers and bulldozers. The decontamination rate would be rather slow. The extent of the effort (this effort may be started after mission re-entry) would depend upon the site and the mission time required in these areas.

The effectiveness of the recovery effort needed in the target complex will depend upon the location of interest within the vital areas. Although the effectiveness as well as effort will vary from location to location, in general the locations of poor effectiveness

can normally be avoided or least traversed, and the areas of higher effectiveness may be selected for the longer occupancy. Conversely the areas in which long stay-times are required may be more thoroughly cleaned to provide adequate protection.

The decontamination rate of 2000 ft^2/team-hour assumed could be maintained at all five refineries. For some, 3000 ft^2/team-hour is possible, in which case the mission re-entry time would not be significantly earlier but the manpower requirements would be substantially reduced.

RN_3 values of 0.2 and 0.1 were used to show that high effectiveness of decontamination is not required over most of the I_s range. For instance, a higher decontamination effectiveness or a smaller RN_3 value than 0.2 for standard intensities less than 5400 r/hr would not permit an earlier re-entry time than that shown in Table 1 because the RN_2, not RN_3 value, was the controlling factor. Furthermore in the higher standard intensity range where the RN_3 values of 0.2 or 0.1 would delay the mission re-entry time beyond the termination of decontamination, the delay applies only for the situation where mission personnel would be exposed to the external residual dose rate 24 hours every day. If it is assumed that adequate shelter would be taken during off-duty hours, the extension of mission re-entry times as dictated by the RN_3 values may be ignored, because the effective RN_3 would be reduced to 1/3 of the given value if the people were exposed to only 1/3 of a 24-hr day. Also if it is assumed that decontamination operations would be continued after mission re-entry and that the initial decontamination effort achieved a RN_3 value of 0.2 or better, the RN_3 restrictions again may be ignored whether or not shelter is used during this phase. The limiting condition for any mission re-entry time then, is the decontamination dose on the first day of decontamination. Consequently if shorter recovery work shifts could be effectively executed, the mission re-entry time would be shortened. On the other hand if some of the industrial plants to be investigated are low in manpower and the total time spent per man on the first day of operational recovery is longer than 5 hr, the mission entry time would be delayed.

At the present state of decontamination technology, much data exist on decontamination effort and effectiveness on plane surfaces. Research has emphasized high effectiveness for various plane surfaces. However, decontamination effort and effectiveness data for a target complex which contains a mixture of surfaces and a complex geometry are meager. For the permissible dose restrictions prescribed in this study a very important parameter is the dose to the decontamination personnel. Hardly any effort has been made to document RN_2 values in the past because of our lack of understanding of the effects of radiation;

however, if the permissible dose figures provided for this problem are realistic, this particular decontamination parameter is of utmost importance and should be thoroughly documented. But this is not all. Since a reduction of RN_2 values would permit an earlier entry time, reducing them either by alternate decontamination methods, by providing protective shielding, or by operational procedural changes should be investigated.

5. CONCLUSIONS

a. The method used for obtaining the earliest mission re-entry times appears to be satisfactory for any target complex and for any dosage criteria.

b. Mission re-entry times for undamaged (either by the attack or by emergency shut-down) petroleum refineries varied from 1 day for a standard intensity of 100 r/hr to 35 days for a standard intensity of 30,000 r/hr.

c. The mission re-entry times were practically identical for all five refineries studied, although their physical layout and mode of operations were quite diverse.

d. The most important factor in determining the mission re-entry time was the dose to the decontamination crews. The need for experimental RN_2 data and means of reducing RN_2 values are vital.

e. Data on decontamination effort and effectiveness for industrial complexes, non-existent today, are required to substantiate the findings of this study.

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7	Chief, Bureau of Supplies and Accounts (Code W-1)
8-9	Chief, Bureau of Yards and Docks (Code 74)
10	Chief, Bureau of Yards and Docks (Code E-400)
11	Chief of Naval Personnel (Pers C11)
12	Chief of Naval Operations (Op-07T)
13	Chief of Naval Operations (Op-446)
14	Chief of Naval Operations (Code 104)
15	Commander, New York Naval Shipyard (Material Lab.)
16-18	Director, Naval Research Laboratory (Code 2021)
19	Office of Naval Research (Code 422)
20	Office of Naval Research (Code 441)
21-35	Office of Naval Research, FPO, New York
36	CO, Naval Unit, Army Chemical Center
37	CO, U.S. Naval Civil Engineering Laboratory
38	U.S. Naval School (CEC Officers)
39	CO, Construction Battalion Center, Port Hueneme
40	CO, Construction Battalion Center, Davisville
41	CO, Construction Battalion Base Unit, Port Hueneme
42	CO, Construction Battalion Base Unit, Davisville
43	CO, Disaster Recovery Training Unit, Port Hueneme
44	CO, Disaster Recovery Training Unit, Davisville
45	Commander, Naval Air Material Center, Philadelphia
46	Naval Medical Research Institute
47	U.S. Naval Hospital, San Diego
48	Director, Naval Weapons Laboratory, Dahlgren
49	CO, Naval Schools Command, Treasure Island
50	CO, Naval Damage Control Training Center, Philadelphia
51	U.S. Naval Postgraduate School, Monterey
52	Commander, Naval Ordnance Laboratory, Silver Spring
53	Commandant, Twelfth Naval District
54	Office of Patent Counsel, San Diego
55	Director, Institute of Naval Studies, Newport
56	Commandant of the Marine Corps

57	Commandant, Marine Corps Schools, Quantico (CMCLFDA)
58	Director, Landing Force Development Center
59	CO, Naval Medical Field Research Laboratory, Camp Lejeune

ARMY

60	Chief of Research and Development (Atomic Division)
61	Chief of Research and Development (Life Science Division)
62	Deputy Chief of Staff for Military Operations
63	Office of Assistant Chief of Staff, G-2
64	Chief of Engineers (ENGMC-EB)
65	Chief of Engineers (ENGMC-DE)
66	Chief of Engineers (ENGRD-S)
67	Chief of Engineers (ENGCW-C)
68	Chief of Transportation (TC Technical Committee)
69	Chief of Ordnance (ORDTN-RE)
70	CG, Ballistic Research Laboratories
71	CG, USA CBR Agency
72	President, Chemical Corps Board
73-75	CO, BW Laboratories
76	CO, Chemical Corps Training Command
77	Commandant, Chemical Corps Schools (Library)
78	CO, Chemical Corps Field Requirements Agency
79	CO, Chemical Research and Development Laboratories
80	Commander, Chemical Corps Nuclear Defense Laboratory
81	CO, Army Environmental Hygiene Agency
82	CG, Aberdeen Proving Ground
83	CO, Army Medical Research Laboratory
84-85	Medical Field Service School, Fort Sam Houston (Stimson Lib.)
86	Medical Field Service School, Fort Sam Houston (Dept.Prev.Med.)
87	Director, Walter Reed Army Medical Center
88	Hq., Army Nuclear Medicine Research Detach., Europe
89	Hq., CONARC (CD-CORG Library)
90	CG, Quartermaster Res. and Eng. Command
91	Quartermaster Food and Container Institute
92	President, Quartermaster Board, Fort Lee
93	Hq., Dugway Proving Ground
94-96	The Surgeon General (MEDNE)
97	CO, Army Signal Res. and Dev. Laboratory
98	CG, Engineer Res. and Dev. Laboratory
99	CO, Transportation Res. and Dev. Command
100	Director, Office of Special Weapons Development
101	Director, Waterways Experiment Station
102	CO, Watertown Arsenal
103	CG, Ordnance Tank-Automotive Command
104	CO, Ordnance Materials Research Office, Watertown
105	CO, Picatinny Arsenal (ORDBB-TW6)
106	CO, Frankford Arsenal
107	Rocky Mountain Arsenal
108	Commandant, Command and General Staff College

AIR FORCE

109	Assistant Chief of Staff, Intelligence (AFCIN-3B)
110-115	CG, Aeronautical Systems Division (ASAPRD-NS)
116	CO, Radiological Health Laboratory Division
117	Directorate of Civil Engineering (AFOCE-ES)
118	Director, USAF Project RAND
119	Commandant, School of Aerospace Medicine, Brooks AFB
120	CG, Strategic Air Command (Operations Analysis Office)
121	Director of Civil Engineering, Offutt AFB
122	Office of the Surgeon (SUP3.1), Strategic Air Command
123	Office of the Surgeon General
124	Commander, Special Weapons Center, Kirtland AFB
125	Directorate of Nuclear Safety Research, Kirtland AFB
126	Director, Air University Library, Maxwell AFB
127-128	Commander, Technical Training Wing, 3415th TTG
129	Hq., Second Air Force, Barksdale AFB
130	Commander, Electronic Systems Division (CRZT)

OTHER DOD ACTIVITIES

131-133	Chief, Defense Atomic Support Agency (Library)
134	Commander, FC/DASA, Sandia Base (FCDV)
135	Commander, FC/DASA, Sandia Base (FCTG5, Library)
136	Commander, FC/DASA, Sandia Base (FCWT)
137	Assistant Secretary of Defense (Supply and Logistics)
138-147	Armed Services Technical Information Agency
148	Director, Armed Forces Radiobiology Research Institute
149	Commander, STRIKE Command
150-199	Office of Civil Defense, Washington

AEC ACTIVITIES AND OTHERS

200	Research Analysis Corporation
201	Aerojet General, Azusa
202	Aerojet General, San Ramon
203	Allis-Chalmers Manufacturing Co., Milwaukee
204	Allis-Chalmers Manufacturing Co., Washington
205	Allison Division - GMC
206-209	Argonne Cancer Research Hospital
210-219	Argonne National Laboratory
220	Atomic Bomb Casualty Commission
221	AEC Scientific Representative, France
222	AEC Scientific Representative, Japan
223-225	Atomic Energy Commission, Washington
226-229	Atomic Energy of Canada, Limited
230-232	Atomics International
233-234	Babcock and Wilcox Company
235-236	Battelle Memorial Institute
237	Beryllium Corporation
238-241	Brookhaven National Laboratory

242	Bureau of Mines, Albany
243	Bureau of Mines, Salt Lake City
244	Chicago Patent Group
245	Columbia University (Rossi)
246	Combustion Engineering, Inc.
247	Combustion Engineering, Inc. (NRD)
248	Committee on the Effects of Atomic Radiation
249-250	Convair Division, Fort Worth
251-253	Defence Research Member
254	Division of Raw Materials, Washington
255	Dow Chemical Company, Rocky Flats
256-258	duPont Company, Aiken
259	duPont Company, Wilmington
260	Edgerton, Germeshausen and Grier, Inc., Goleta
261	Edgerton, Germeshausen and Grier, Inc., Las Vegas
262	Franklin Institute of Pennsylvania
263	General Atomic Division
264-265	General Electric Company (ANPD)
266-269	General Electric Company, Richland
270	General Electric Company, St. Petersburg
271	General Telephone and Electronic Laboratories, Inc.
272	Gibbs and Cox, Inc.
273	Glasstone, Samuel
274	Goodyear Atomic Corporation
275	Grand Junction Office
276	Hawaii Marine Laboratory
277	Hughes Aircraft Company, Culver City
278	Iowa State University
279	Journal of Nuclear Medicine
280-282	Knolls Atomic Power Laboratory
283	Lockheed Aircraft Corporation
284-285	Los Alamos Scientific Laboratory (Library)
286	Lovelace Foundation
287	M and C Nuclear, Inc.
288	Mallinckrodt Chemical Works
289	Maritime Administration
290	Martin Company
291	Massachusetts Institute of Technology (Hardy)
292	Mound Laboratory
293	National Academy of Sciences
294	NASA, Lewis Research Center
295-296	NASA Scientific and Technical Information Facility
297-298	National Bureau of Standards (Taylor)
299	National Cancer Institute
300	National Distillers and Chemical Corporation, Bridgeport
301	National Distillers and Chemical Corporation, Ashtabula
302	National Lead Company of Ohio
303	National Library of Medicine
304	New Brunswick Area Office
305	New York Operations Office
306	New York University (Eisenbud)

307	Nuclear Materials and Equipment Corporation
308	Oak Ridge Institute of Nuclear Studies
309	Patent Branch, Washington
310-315	Phillips Petroleum Company
316	Power Reactor Development Company
317-319	Pratt and Whitney Aircraft Division
320	Princeton University (White)
321	Public Health Service, Las Vegas
322	Public Health Service, Montgomery
323-324	Public Health Service, Washington
325	Rensselaer Polytechnic Institute
326	Sandia Corporation, Albuquerque
327	Sandia Corporation, Livermore
328	Schenectady Naval Reactors Operations Office
329	States Marine Lines, Inc.
330	Sylvania Electric Products, Inc.
331	Technical Research Group
332	Tennessee Valley Authority
333-334	Union Carbide Nuclear Company (ORGDP)
335-341	Union Carbide Nuclear Company (ORNL)
342	Union Carbide Nuclear Company (Paducah Plant)
343	United Nuclear Corporation (NDA)
344	United Nuclear Corporation (OMC)
345	U.S. Geological Survey, Naval Gun Factory
346	U.S. Geological Survey, WR Division, Washington
347	U.S. Weather Bureau, Las Vegas
348	U.S. Weather Bureau, Washington
349-353	University of California Lawrence Radiation Lab., Berkeley
354-355	University of California Lawrence Radiation Lab., Livermore
356	University of California, Davis
357	University of California, Los Angeles
358	University of California, San Francisco
359	University of Chicago Radiation Laboratory
360	University of Puerto Rico
361	University of Rochester (Atomic Energy Project)
362	University of Tennessee (UTA)
363	University of Utah
364	University of Washington (Donaldson)
365-368	Western Reserve University (Friedell)
369-370	Westinghouse Bettis Atomic Power Laboratory
371	Westinghouse Electric Corporation (Rahilly)
372	Westinghouse Electric Corporation (NASA)
373	Yankee Atomic Electric Company
374-398	Technical Information Service, Oak Ridge
399-423	Office of Technical Services, Washington

USNRDL

424-475	USNRDL, Technical Information Division

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A METHOD FOR DETERMINING MISSION RE-ENTRY TIMES FOR FALLOUT-CONTAMINATED INDUSTRIAL COMPLEXES by H. Lee 9 March 1962 28 p. tables illus. UNCLASSIFIED

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(over)

1. Industrial plants - Decontamination.
2. Refineries - Decontamination.
3. Radiological contamination- Mathematical analysis.
4. Fallout- Countermeasures.

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